GRAVIMETRIC AND VOLUMETRIC FEEDING
OF PARTICULATE SOLIDS

PARTICULATE SOLIDS, BIN HOPPER AND METERING –
BASIC FUNDAMENTALS

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INTRODUCTION

The tremendous volume of bulk particulate solids currently being handled in the processing industries has reached such proportions that the costs involved have prompted many in the various industries to re-evaluate their handling systems with respect to reducing operating costs and increasing operational efficiency. The problem is encountered by both the processor and manufacturer of the various particulate materials being utilized. The flow characteristics of the materials vary widely from free flowing pellet materials to extremely flow resistant, finely divided powders and light bulk density, hard to handle regrinds and scrap. It is estimated that the plastics industry alone handles more than 24 billion pounds of these various types of materials per year. With such large quantities of raw materials, coupled with an annual growth rate of better than 9 percent for the industry, it is easy to see that the storage, recovery and feeding of bulk particulate solids are demanding increased attention on all plant levels. [1] [13]

Until recent years, the storage and recovery of particulate solids was often neglected by plant operators. Their prime interest was more on production and storage capacity with little consideration to handling. Inadequate attention to these matters at the time of designing a system or lack of reliable data for properly designing a system resulted in a multitude of problems being experienced when the plant went “on stream” or became fully automated. In a fully automated system, the “human assist” to eliminating flow stoppages and related problems is nonexistent. The fully automated system must compensate for known variables and projected problems.

The major requirements for any bulk solids handling system are that the material be readily discharged from holding bins, on demand, and in a controlled volume — even after prolonged shutdowns, such as weekend periods. Provisions for starting and stopping the discharge as well as regulating material flow to satisfy system use rates, both upstream and downstream, are critical. Material rate repeatability, in continuous and batch feeding operations, is essential. The key to a successful particulate solids handling system is, therefore, divided into two related areas — reliable, uniform discharge of material from the storage bin and controlled feed or metering into process.

STORAGE BINS

In order to satisfy process requirements, raw materials must be stored in sufficient quantities, such that they are readily available for production purposes when required. The supply of these raw materials must flow on demand, and without interruption. To operate at maximum efficiency, the process industries cannot await the shipment of raw materials prior to the production of their eventual, final product. Storage bins of sufficient volume are, therefore, required to eliminate “downtime” that results in the interruption of material flow from the supply sources to the user. The de-
sired inventory of raw materials will vary from product to product throughout the processing industries. Material availability, cost, storage characteristics, transport lag time, and use rates are many factors affecting the quantities of raw materials held in storage.

Once the decision has been made as to the volumetric capacity of each raw material storage bin, consideration should be given to the methods used in providing a constant, uniform discharge of these materials, on demand, from the storage bin. There are currently two dominant approaches to achieving controlled flow of material from storage bins. One involves bins designed to promote unassisted gravity flow, based on a mathematical analysis of the material’s flow characteristics. The other approach is based on the use of mechanical devices to promote flow. The design of storage bins, according to mathematical analysis of the material, is restricted to new bins only, while the application of mechanical devices can be used on either new or existing bins of various configurations.

The selection of what type of method to apply to the bin discharging problem will depend upon the material or materials to be handled and their basic characteristics along with the type of metering equipment that will be used. The need to feed the recovered material into process with repeatable accuracy is second in importance only to the controlled flow from the holding bins. All feeders, whether volumetric or gravimetric, require a steady supply of material at a uniform bulk density at their input for maximum operating efficiency and accuracy.

It is generally recognized that the terms bunker and bin are synonymous, whether for vertical or horizontal containers, with or without hoppers. The vertical portion being called the bin; the sloping portion, the hopper. Quite frequently used in the “heavy” industries (height equals width).

A silo is generally a tall and narrow container (height greater than width). Most common in agricultural, chemical, plastics and petrochemical industries. Diameter to height will vary from application to application. Vertical heights of 2 to 6 times the diameter are common. [4]

**PARTICULATE SOLIDS**

The most important item in designing any solids handling system is the material to be handled. The basic characteristics of the material will determine, in many cases, storage bin capacities, configuration, contact materials, metering device or devices, and other process components. An understanding of a material’s characteristics and how to apply these characteristics are essential when designing or modifying any solids handling system.

**BULK DENSITY**

A material’s bulk density is a comparison of the material’s weight per given unit of volume, i.e. pounds per cubic foot, grams per cubic centimeter, kilograms per cubic meter, etc. Bulk density is further defined as loose, packed, and dynamic. Test procedures have been established for determining bulk density. For example, the standard method to determine the bulk density of aggregate is described in ASTM No. C29-60, bituminous coal in ASTM-291-60, coke in ASTM D292-29. [1] Bulk density is important in determining the physical properties that must be incorporated in the design of storage bins and metering equipment. Large differences between a material’s loose bulk density in comparison to the packed bulk density is an indication that the material may be either easily fluidized or extremely pressure sensitive. A material made up of different types of ingredients (mixtures) where each has a different and specific bulk density, will tend to separate or segregate to separate units. Generally, granules are denser and freer flowing than the less dense powdered particles that are non-free flowing in nature. A material whose bulk density changes from supplier to supplier and with changes in atmosphere, may not be suitable for handling with volumetric discharging and metering equipment.

**MOISTURE CONTENT**

Moisture content is divided into two specific groups, inherent (water of hydration) and surface moisture. Inherent moisture content refers to moisture contained in the particle as part of its chemical composition. I.e. FeCl₃·6H₂O. Surface moisture is, as the name implies, water that is contained with the material in question. Moisture content affects solid materials in many different ways. An increase in moisture may result in the material becoming freer flowing, such as in the case of sand or coke breeze and many other, granular materials. The water acts as a “lubricant”, reducing the frictional effects one particle has upon the other, thus increasing the flowability of the material. Some materials, however, such as color concentrates,
flour and other finely divided powders with non-uniform particle shapes become more difficult to discharge from storage and meter into process. In such cases, the water acts as a bonding agent between particles. Van der Waal’s forces also influence the individual particles with higher concentrations of water.

Moisture content is further defined as the ratio of the weight of water to the weight of dry solids in a given quantity of material. [2] The addition of water to dry solids will also affect the material’s bulk density.

Moisture content plays an important part in selecting bin discharging devices and metering devices. Moisture content should not be confused with solvent, fat or oil content.

If moisture contents cannot be controlled, and will present handling problems in a semi-dry state, consideration should be given to handling the material in a slurry.

Slurries will not be dealt with in this paper.

PARTICLE SIZE

Material particle size is a derived property pertaining to the entire mass of particles. [2] A screen analysis and visual inspection of a material show that particle size and quantity of each specific size and shape of the individual particle will vary within a single material type. Particle size distribution plays an important part in the design of the storage bin and application of the specific metering device required for rate control. A screen analysis should be conducted on the material being used and a particle size distribution curve established. The distribution curve will assist the designer in determining if the material will readily segregate upon addition into the storage bin, or discharging from the metering device into process, or if the material will flow down a chute.

ANGLE OF REPOSE

A material’s angle of repose is defined as the angle, from the horizontal, that the material assumes when at rest, from the top of the pile to its base. [1] Angle of repose is useful for determining actual bin storage capacity, the location of level sensors and also gives an indication of the material’s flowability. The angle of repose of a material is generally constant, but will vary with changes in moisture content, particle size distribution, temperature and operating pressure differentials.

ANGLE OF SLIDE

The angle of slide of a material is the angle to the horizontal of an inclined flat surface on which a given quantity of material will begin to slide downward by its own weight. [1] The angle of slide will vary with moisture content, particle size and configuration, type of surface the material is coming in contact with, the rate of change and condition of the sloping of the surface. It is also referred to as the adhesiveness of the material to a dissimilar surface. Angle of slide is especially useful in the design of hopper angles, chutes and other inclined surfaces.

TEMPERATURE

Temperature gradients may affect a material if the temperature involved induces a physical change or initiates a chemical reaction. Temperature changes can result in condensation forming within storage bins, metering devices, etc. Pelletized material containing latent heat, when placed in the storage bin, can result in a resolidification of all particles into a single mass or masses of considerably larger sizes that will not flow out of the storage bin and will not be successfully metered. Heat generated from the processing equipment, if any, should not initiate a chemical reaction that could be obtained with endothermic materials.

PRESSURE

Pressure differentials must be considered in the design of bulk solids handling systems. Pressure differentials, whether positive or negative, can be caused by the method used to convey the material into the storage bin, or may be induced in the form of an inert atmosphere as part of a process. Pressure differentials will affect the hoppersing and metering of the material being designed for.

ABRASIVENESS

Abrasiveness is defined as the material’s ability to abrade or grind away the surface of other materials it comes in contact with. [2] A material’s abrasiveness will determine the type of contact material used in the storage bin and metering device. Extremely abrasive materials will require wear plates or liners within the storage bins and separate consideration must be given to the type of metering device used.
COHESIVENESS

Cohesiveness is defined as the extent individual particles tend to cling together or form an interparticle bond. A material with cohesive tendencies will tend to bridge or dome within a storage hopper. Cohesiveness is a result of one or more of the following: Van der Waal’s forces, surface tension, particle shape, moisture or solvent content, interparticle friction or electrostatic attraction. [3]

MATERIAL MELTING POINT

The type of conveying equipment selected should not introduce heat into the system that will cause a physical change in the material being handled.

HYGROSCOPICITY

A material is hygroscopic if it has a tendency to “pick up” moisture from the surrounding atmosphere. [3] Hygroscopic material will tend to “cake up”. Some materials will physically deteriorate when stored in open bins and may take on a condition similar to a slurry. Materials of this nature will require an enclosed system where a dry, inert gas is substituted for ambient air. Changes in particle size, due to hygroscopicity, can seriously alter the flow of material from the storage bin and metering device selected.

PARTICLE ATTRITION

Consideration must be given to the conveying and metering equipment if the material particle size is subject to a change in the conveying process. Particle attrition will result in bulk density variations and in its basic flowability as well as the quality of the ultimate product being manufactured.

The careful application of process equipment, utilizing the fundamental handling characteristics of the material to be handled, is essential to a successful installation.

STORAGE BINS – FEEDERS

When designing bins for mass or gravity flow, all material characteristics previously mentioned, and others, must be considered. In addition, in actual operation, these characteristics should be held constant for optimum system performance.

Mechanical bin discharges are not generally restricted to a material of a specific nature. In many cases, different materials are stored in a single bin (at different times) and are successfully discharged and metered on demand.

The difference between the two concepts is that mass flow or gravity flow bins rely on, as the name implies, gravitational effects for discharge. In some materials, the interparticle actions taking place within the bin may exceed the effects gravity plays in the discharge of material and circumvent the initial design criteria.

Mechanical bin dischargers apply energy into the storage system for the purpose of discharging material. The amount of energy input, in many cases, is variable and will compensate for material characteristic changes.

Metering or feeding equipment is, on the other hand, very susceptible to material characteristic changes. Bulk density, moisture content, and particle size, to mention a few, will affect a volumetric feeder tremendously.

Volumetric feeders deliver a given volume of material per unit time. A change in material bulk density, for example, will result in a proportional change in the discharge rate.

Gravimetric or weigh feeders meter material according to weight and are not affected by bulk density changes. Gravimetric feeders compensate for the majority of material characteristic changes that may take place within the handling system.

The efficiency of both volumetric and gravimetric feeders is enhanced by a uniform and continuous supply of material, on demand, from the storage bin.

DISCHARGING PARTICULATE SOLIDS FROM STORAGE

The flow of particulate solids from storage has been examined by many authors. The techniques involved in flow mechanics have been thoroughly described in qualitative and quantitative terms. The work of Carr, Colijn, Jenike, Wahl, Johanson, Lee, Fowler, to name a few of the more distinguished researchers, has resulted in considerable expertise being developed and practical solutions to bin discharge problems being brought forth.

Mass flow or plug flow bins are, by definition, storage bins whose design is related to the handling characteristics of a specific material in a given condition (Fig. 1). All material contained in the storage bin is in motion whenever material is being
withdrawn. Material flow is on a first in — first out basis. Mass flow bins can take many shapes and forms from circular to chisel shaped, to positive or negative sloping hoppers. Discharge outlets, size and shape, are also determined through a sample examination and the application of the data obtained within the established formulae.

BIN HOPPER DISCHARGING DEVICES

Many different types of bin hopper discharging devices have been developed over the last 100 years. The simplest method of discharging material from the storage bin would be to incorporate "poke holes" where manual prodding is required to eliminate material bridging within the hopper section. Manual control requires the constant attention of plant personnel, however, [4]

In some applications, elements suspended from above the bin, such as steel chain or cable, have been used in an attempt to reduce material bridging within a hopper. [4] Frequent agitation of the chain or cable from an overhead crane is required.

Agitators or "rotating fingers" have been used with limited success. These rotating agitators are installed in the outlet of the hopper and rotate on a horizontally mounted drive shaft. The metal "fingers" are designed to break up material compaction at the hopper outlet.

Sweep arms or rotary vanes are sometimes installed in the hopper section of the bin. (Fig. 2) The sweep arm is coupled to drive a motor, via a Universal coupling located beneath the outlet. The sweep arm rotates about the conical hopper section of the bin. This type of arrangement is designed to remove the pressure of material against the hopper walls thus eliminating bridging within the hopper section. The upper end of the sweep arm or vane rubs against a wear plate.

Rotary plow feeders have been used to discharge material from bins with slotted bottoms. The rotary plow moves along a horizontal plane parallel to the slotted opening in the storage bin. A revolving vane or plow scoops the material out of the slotted opening and into a gathering trough. (Fig. 3) This type of arrangement is integrated with auxiliary gathering equipment, such as a belt or screw conveyor for furtherance to process.

Multiple screw bottoms are quite frequently used on stringy or severely interlocking materials, such as those found in the wood process industries. (Fig. 4) This type of arrangement utilizes screw feeders as the entire bottom or hopper of the bin.

The Bin Activator has proven to be industry's most positive and reliable discharging device. [5] (Fig. 5)

The Bin Activator, invented by Mr. E. A. Wahl in 1960, is essentially a vibrating section which is flexibly attached to the bin and replaces some or all of the hopper section. The Bin Activator is attached at the potential compaction zone. The method of attaching the Bin Activator to a bin and the principles of operation are shown in Fig. 6.

Since most flow problems are caused by compaction in the hopper section of a static bin, the compaction zone is removed. With the compaction zone removed, the flow pressure is reduced. Material would now flow by gravity. In many instances, once the compaction zone has been removed, the resultant opening is too large to readily adapt any metering device to it.

The Bin Activator couples the large opening to the metering device mounted beneath and provides flow control from this enlarged opening. The Bin Activator is flexibly mounted to the hopper section with rubber fitted, forged steel hangers which provide vertical rigidity and horizontal flexibility. A gyrator is attached to the vibrated bottom that produces powerful horizontal thrusts which vibrate the discharger but not the bin. An integral, vibrated baffle located above the discharge outlet carries a headload of material in the bin, preventing compaction at the outlet. The baffle also transmits vibration perpendicular to its surface into the material above the Bin Activator. This transfer of vibration prevents material bridging within the bin.

The Bin Activator size is determined primarily by the handling characteristics previously mentioned and the diameter or cross-sectional area of the bin. As a general rule, for handling granular, free flowing materials, such as plastic pellets or pelletized colorant, the Bin Activator diameter should be 1/4 to 1/2; for adhesive powders or easily fluidizable powders, such as PVC resin and some color concentrates, 1/2 to 2/3; and for fibrous, flaky, severely interlocking materials, the Bin Activator diameter should be the same diameter as the bin to which it is being attached.

The Bin Activator is primarily a flow promoting device and not a feeding device. In many applications it does, however, perform both functions. Material flow is at a consistent, uniform bulk density. [5]

Highly fluidizable or aerated materials may be densified within the bin by the vibratory forces developed by the Bin Activator. Entrained air is
released from the material and the product is densified. Material is discharged into the metering device at a uniformly dense state. This eliminates the requirement of rotary vane type feeders, except when pressure differentials exist.

In many installations, the available clearance for holding bins, day or use bins, is limited. Gravity flow or mass flow bins being tall with respect to their capacity, frequently have to be extended through the floor, either above or below the process area. Other devices require less headroom. Bin Activators, on the other hand, are adaptable to any bin and require as little as 3 ft. of headroom for a 6 ft. diameter unit.

Electromechanical devices, such as side vibrators, have been used to promote material flow from storage hoppers. (Fig. 6) Side vibrators provide a localized effect on material within the storage bin. Side vibrators do not eliminate the compaction zone within the hopper section and in some cases aggravate or increase the compaction problem.

Pneumatic and hydraulic vibrators have been used with the same degree of success as experienced with the electromechanical type side vibrators.

Air pads, cushions and slides have been used with success on many materials. Devices of this nature incorporate the injection of air into the product being stored. Air is used to fluidize the material and reduce or eliminate the compaction or bridging zone. The effect of air on a product, whose particle size and weight vary, has been questioned. Materials that are fluidized tend to take on liquid characteristics and must be handled with special precautions.

Hence, as one can readily see, there are many options available to the designer for providing a discharge of material from the storage bin on demand. The next problem to be confronted with is the metering of feeding of the material into process.

FEEDERS

Feeders or metering devices are divided into two categories: volumetric and gravimetric.

Volumetric feeders rely on a uniform supply of material from the storage bin at a consistent bulk density for their operation. Volumetric feeders meter material in direct relation to the capacity of the transfer or conveying media. The discharge rate is dictated by the volume of this media, rotational or translational speed, bulk density, and the flow factor of the metered product.

Volumetric feeders are available in many forms from vibrating screw feeders to table feeders. Feed accuracies will vary from 1 percent to 15 percent, depending upon type and prefeed device being utilized.

Volumetric feeders are used in many cases as prefeeding devices for gravimetric type feeders. Screw, belt, vibrating pans, rotary vane and vibrating screw feeders are some of the volumetric feeding devices currently available to the process engineer. The vibrating screw type feeder is the most accurate and consistent volumetric feeding device of the above mentioned feeders. (Fig. 8)

The vibrating screw type feeder utilizes vibration of the screw, tube and trough assembly to assure a uniform and consistent filling of each flight of the metering screw and assures a complete discharge of the material at the discharge end.

Accuracy and dependability of a similar nature are obtained if the belt feeder is used in conjunction with the vibrating Bin Activator, previously described. A nozzle is attached to the Bin Activator outlet, vibrating with it, providing a uniform ribbon of material to the belt surface. (Fig. 9)

The selection of a volumetric feeding device, to be used as a prefeed to a gravimetric feeding device, is subject to close examination of the material being handled. For example, interlocking materials, such as fiberglass or reground scrap, are readily handled using a vibrating screw type feeder. A belt, vibrating pan, static screw or rotating vane feeder would encounter problems due to the material bridging or doming across the feeder inlet. In addition, pan or belt type feeders would probably experience problems of the material not shearing at the nozzle between the adjustable gate and feeder surface, either the belt surface or pan surface.

Volumetric feeders can further be classified as “open loop” feeders. Open loop refers to the nonexistence of feedback information from the process to the controller. This is true whether the volumetric feeder is operated in batch or continuous modes. A good example of open loop is a washing machine operating through various cycles. [6] No inspection is given to the operation until the final inspection by the operator. A visual inspection may reveal that additional washing, etc. is required and the cycle repeated.

GRAVIMETRIC FEEDERS

Gravimetric feeders are utilized where an accurate control of material is necessary. Gravimetric
feeders are especially useful when handling a material whose basic physical characteristics vary. Gravimetric feeders meter and control the rate of discharge irrespective to material changes.

A gravimetric feeder can be utilized in several different ways: continuous metering with control, wild flow and as a batching feeder.

Gravimetric metering devices meter material as a direct function of weight per time interval. A weight sensing device and velocity transmitter send a signal to a multiplier where the two signals are integrated. The output from the multiplier represents an electronic equivalent to the amount of material being metered at that instant. This electronic equivalent is compared to an electronic signal of precise value, that is equivalent to the desired feed rate. Any discrepancies between the two signals result in corrective action being taken by the belt drive motor, changing velocity (increasing or decreasing).

Gravimetric feeders are divided into two groups: continuous and batch.

Feed accuracies will vary from 0.15 percent to 1 percent. Accuracy is not generally related to bulk density or changes in metered material.

There are several advantages of converting conventional batch processing operations to a continuous process. Batch processes, in most industries, have common operating characteristics. [7]

1. All are cyclic, that is repeatedly going through fill-store-empty cycles.
2. All require possible post-weigh addition of material, commonly referred to as “topping off.”
3. A control system for a batch process must provide not only feedback control, but also a means for varying operating conditions as a function of time.

The general trend today is toward weighing materials on the move. [7] The big advantage of continuous weighing is the ability to precisely meter large quantities of material in less time than that of a batch system. Among the benefits obtained from continuous processing are higher production rates, reduced plant costs per unit of production, lower unit investment, lower operating costs, and more uniform quality. Contrary to many beliefs, the operation and design of continuous weighing equipment is much simpler than automatic batching systems, which require more components and complex circuitry.

**TYPES OF GRAVIMETRIC FEEDERS**

There are four basic types of gravimetric feeders. [8]

The first type, that which was used on the first generation of gravimetric feeders, utilizes a weight counterbalance. This type of unit uses a weight of known value to counterbalance a metering belt with a desired feed weight (rate). This is accomplished through the utilization of levers. This type is most similar to the balance beam scale. (Fig. 10)

The deflectional or spring counterbalance type feeder senses a load across its belt. The load causes an elastic element to deflect, either tension or compression and within the elastic limits of the material, through the position of equilibrium where the internal forces resist the load force applied. These forces are sent by either strain gage load cells or linear voltage differential transformers. This type of unit is most often used in today’s gravimetric feeders.

The pneumatic or hydraulic force counterbalance type feeder is similar to the deflectional or spring counterbalance feeder described above. This type of unit utilizes a hydraulic or pneumatically generated pressure signal that becomes a counterbalancing force. Weight is directly related to the pressure being sensed and is converted and controlled accordingly.

The last type of gravimetric feeder utilizes nuclear radiation. Radiation is directed at a flow of material on a belt. This type of unit uses the absorption of energy as related to the mass of the absorbing material. Conversion and control then take place. This type of unit has not, to date, been fully exploited.

**BASIC DEFINITIONS AND TERMS** [9]

Prior to selecting any type of gravimetric feeder, a basic understanding of the terms used in the continuous weigh feeder market would be helpful.

**ACCURACY**

Accuracy is a major consideration in any application involving gravimetric feeders. Accuracy has many meanings. When evaluating a process control application, however, accuracy is related to system accuracy where a sum total of all variables is considered. System accuracy is directly related to sensitivity of the weighing unit, the resolution displayed by a given weighing unit, repeatability of the system and “dead time” or lag time.

**CALIBRATION**

This is a comparison of the weigh cell output against a standard test load. The type of calibration
of a weigh system will vary from manufacturer to manufacturer.

"DEAD TIME" (LAG TIME)

"Dead time" or transport lag time is the time interval that expires between the moment a weight change is introduced onto the weigh element of the feeder and the moment the output begins to change. "Dead time" results in the feeder hunting or cycling. The less "dead time" or lag time in a system results in a more efficient system.

DRIFT

Drift is a random change in output, either of the weight sensing device or control system, under constant load and ambient conditions. Obviously, a minimum amount of system drift is desirable in any process industry.

"RANGEABILITY"

"Rangeability" is defined as a feed range i.e. 10:1, 20:1, 30:1, etc. In gate control systems, the "rangeability" is the ratio of the mass flow through a wide open gate to the flow at the minimum controllable opening. De-control has limited "rangeability." Greater "rangeability" is obtained through the utilization and control of belt speed.

"REPEATABILITY"

This is the maximum difference between loads added to the system with respect to repeated loads under identical loading and environmental conditions. For example, if the feeder indicates a weight of "X" pounds being applied at time (T-1), the same load should also be indicated at time (T-2). If this is not the case, the "repeatability" of the system is poor.

RESOLUTION

Resolution is the smallest increment displayed on a weighing unit. If, for example, you desire to meter material into process with system accuracies to 1/100 of a pound, a scale that indicates feed rate in hundredths of a pound is required. Scales indicating in tenths of a pound would leave the second digit to the interpolation of the operator.

SENSITIVITY

This is the ratio of the change in the system output to the change in mechanical input. Sensitivity may vary with changes in ambient conditions. A good quality feeder maintains its sensitivity throughout many process variables.

SPAN – (RATED OUTPUT)

This is defined as the load, minimum to maximum, that the system is designed to measure and control within its specifications.

ZERO BALANCE/ZERO SHIFT

Zero balance refers to the output of the load sensing device with rated excitation and with no load applied. This is usually expressed in percent of rated output.

Zero shift refers to a change in the zero balance. Some gravimetric feeders require adjustment to the scale zero balance prior to use. Good quality gravimetric feeders incorporate automatic zero to eliminate readjustment of the zero prior to use.

All of the above are directly related to system accuracy, which determines the quality of control.

PRINCIPLES OF THE GRAVIMETRIC FEEDER

The operation of the gravimetric feeder, as used in a system, is divided into four areas: [8] Material from the storage hopper, prefeed, weight sensing system, and discharge, either into process, or some other take-away device.

Material flow from the storage hopper has been discussed previously.

Prefeeding devices are an important part of the gravimetric feeder. Prefeeding devices are required in cases where the metered material will not readily flow onto the weight sensing belt, is extremely fluid, or where differential pressures exist between the storage bin and feeder. A good example would be applications concerned with the metering of flaky or fibrous materials, such as ¼" fiberglass strand or chopped film scrap. These materials cannot be uniformly applied to a belt type gravimetric feeder directly from the supply hopper. Vibrating screw prefeeders are required on these and similar materials. Highly fluid materials, such as the various grades of polymer powders used in the plastics
industries, would require a Bin Activator or rotary valve as prefeeding devices. The Bin Activator can be used in lieu of the rotary valve because of its tendency to deaerate or densify the material at the discharge nozzle. Vibrating pan feeders, vibrating screw feeders, belt feeders, rotary valves, and "static" screw conveyors all have been used successfully as prefeeding devices.

Once the material has been successfully discharged from the storage hopper, a prefeed device, if required, is selected. The next consideration should be to the type of weight sensor utilized. There are many different types of gravimetric feeders on the market today using a variety of weight sensing systems. These will vary from the balance beam type, previously mentioned, to the deflectional or spring counterbalance type.

The deflectional or spring counterbalance type is the most commonly used system on today's modern gravimetric feeders. Many different types exist within this category. Some manufacturers will use a weigh platform beneath the conveyor belt. (Fig. 11) The weigh platform is pivoted at one end on a flexure or pivot point. The other end of the weigh platform is supported by a weight sensor. The weight sensor can either be hydraulic, pneumatic or electrical, such as a strain gage load cell or linear voltage differential transformer.

The conveyor belt is usually a very thin, light weight material. This is required to eliminate catenary effects between the weigh belt and weigh platform. With this type of system, care must be given to belt tension, and uniformity. A change in either one will result in a change of sensed weight traversing the weigh platform. This will result in a proportional change in feeder output and accuracy.

The other type of unit utilizes the suspension of the entire weigh belt assembly, motor drive and tachometer between a stable flexure and weight sensing device. (Fig. 12) The input end is supported on frictionless, corrosion free, temperature compensated Inconel "X" flexures. A linear voltage differential transformer supports the discharge end. Material on the entire weigh belt assembly is constantly sensed and correction, if needed, performed. This type of system is not subject to variations in conveyor belt tension or uniformity.

A basic consideration for either type of feeder was the effect of material headload. [10] The headload, material weight from the nozzle, screw or rotary vane type prefeeders, could adversely affect the weigh belt. To eliminate this problem, the two designs mentioned above, require the deposit of material on the belt at the so-called "dead", or least sensitive area of the weigh belt. In the first concept, the material is deposited on a stationary section of the weigh belt, thus utilizing a small section of the belt as a weigh platform. This arrangement eliminates the problem of headload, but also reduces the quantity of material weighed. Changes in belt tension reduce in-system sensitivity. In the second design, the material is deposited at the pivot point, the headload or impact of material onto the belt has no sensed effect. This method allows the material on a belt to be weighed, irrespective of belt tension.

The type of take-away device, if required, will vary from process to process. If the gravimetric feeder is discharging into a differential pressure, a rotary valve or some other suitable pressure sealing device is required, or design the belt enclosure to meet the differential pressure.

TYPES OF CONTROL

The two types of control systems most commonly used today are analog and digital control. An analog controller continuously controls a measured rate of feed at the rates set on the instrument. [11] Feeders utilizing analog control are composed of several analog devices. These devices are all integrated to produce a single desired result. The weight sensing device, either strain gage load cell or LVDT, is an analog device. The analog system controls a measured rate of feed at the rate set on the instrument.

Digital feed control compares the instantaneous weights of materials instead of comparing weight rates. Each pulse in the control network represents a fixed weight of feed. Digital control systems utilize an analog weight sensing device – strain gage load cell or LVDT. (Figs. 12A & 12B)

Both types of control offer the same approximate feed accuracies. Analog feeders, with a little refinement, are easily adapted to computerized systems when incorporated with binary coded decimal output features.

TYPES OF CONTROL LOOPS

The two most common control loops are open loop and closed loop. [12]

Open loop was previously described and is similar to volumetric feeding. One loop control involves feeding material in a quantity necessary to obtain a desired objective. No check is made to de-
termine if the quantity of material applied is cor-
rect or has accomplished the desired objective.

Closed loop control is divided into two groups,
feedback and feed forward. (Fig's 13 & 14)

The early history of feedback control dates back
before the nineteenth century. [1 1] James Watt's
centrifugal governor, invented in 1788, was the
first feedback device to attract the attention of the
whole engineering community and to be interna-
tionally accepted.

This innovation resulted in drastic increases in
feedback control devices. Closed loop control uti-
izes information obtained from a process variable
under control, by a suitable means of measure-
ment, such as a weight sensor, specific gravity
meter, pH meter, etc. that becomes an input to
the controller. An error detecting device (compar-
otor or “balance bridge”) within the system com-
pares this input to a correlated signal representing
the desired condition (set point) and any differ-
ence causes the controller to generate a corrective
signal that is applied to the final control element,
such as belt speed, nozzle opening, etc. A change
in this element results in a proportional increase or
decrease of material going into the system.

Feed forward control is one of the newest forms
of control. In feed forward control, the appropri-
ate measurement sensor is located upstream of the
process. [6] A signal emanates from this measure-
ment sensor that is sent to a reference point with-
in the feeder control. Any corrective action is then
taken. Feed forward control does rely somewhat
on a prediction. This varies from open loop control
in that it does not rely on a fixed program of addi-
tion of material into process. As changes in the in-
put are detected by the measurement sensor, cor-
rection action is taken immediately.

In feedback-closed loop control, a feeder is lo-
cated at the input of the process. Output from the
process is measured and a signal from a measure-
ment sensor is sent back to the reference point
controller. The controller then initiates any correc-
tive action required. A difference between desired
result and actual result is required before any cor-
rective action is taken.

TYPES OF CONTROL MODES

The types of controllers and control loops have
been discussed. How the control system works will
now be considered. There are three basic control
modes: [6] proportional control, reset control,
and derivative or rate action.

All three modes are related to the response
characteristics of the system. The mode of control
selected for the particular process will depend on
many factors, such as: [6]
- Economics
- Preciseness of Control
- Time and Gain Response of the Process
- Safety of Operating Personnel and
- Process Equipment

PROPORTIONAL CONTROL

Proportional action is a controller response
which is proportional to the deviation being sensed.
Proportional control (only) acts on an error signal
being generated from a sensing device located be-
 tween the measured variable and the set point.
Proportional control attempts to return the meter-
ing device to the original set point after a load up-
set has occurred. In actual practice, it is impossible
for the proportional (only) controller to return to
the exact rate previously used.

RESET CONTROL

Once an error has been corrected in a propor-
tional (only) controller, an offset remains. Offset
is the difference between the actual feed rate and
the desired set point after a change has occurred
and equilibrium has once again been established.

If this offset action cannot be tolerated, the
controller should have reset action incorporated.
Reset action involves a controller's response which
is proportional to the extent and duration of the
deviation. In other words, reset action will inte-
grate any differences between the actual run rate
and set point. This will cause the controller's out-
put to change until the difference between the
actual output rate and set point is zero. The time
required for this reset action is adjustable and is
incorporated in the initial design of the controller.

Most controllers used in industrial processes in-
corporate proportional plus reset modes. This is
true whether the feeders use pneumatic and electric
analog or digital control.

DERIVATIVE (RATE ACTION)

Derivative or rate action is a controller's re-
sponse which is proportional to the rate of change
development. Deviation action is used if the re-
sponse time of the process is excessively long.
Stated simply, it is a time difference required to
get to a specified output level. Derivative action will assist the controller in overcoming system inertia.

High quality gravimetric feeders will incorporate all three modes in their control system.

**TYPES OF GRAVIMETRIC SYSTEMS**

Many different types of feeding systems exist where continuous weighing equipment is used. These include:

1. **Single unit metering** — Generally used where a single ingredient must be accurately metered into process. This type of system may receive an external signal from a downstream process. Some examples of this type of system are control of material to extruders, mixing systems, and the control of materials to pelletizers, briquetters, etc. (Fig. 15)

2. **Wild flow — solid additive** — This type of control is used where a small quantity of additive material is required onto a large and uncontrolled rate of bulk material.

   The major quantity is weighed by means of a belt type scale that sends a signal to the weigh feeder. This type of control is most often found in the heavy processing industries, such as the cement or ore aggregate field. (Fig. 16)

   Wild flow — liquid additive — This is identical to the above, only a liquid is the major source being sensed by a flow meter. This type of system is frequently used in the formulation of PVC slurries. (Fig. 17)

3. **Multi-unit — Master-Slave Control** — Master-Slave control systems have found many uses where the minor ingredient being metered (slave) must follow changes in the major ingredient’s (master) flow rate. Changes in the master ingredient rate will result in a change in the rate of slaved material(s) regardless of the cause of change. (Fig. 18)

   Multi-unit — Master Control — This type of control uses a single master control that allows an increase or decrease in the total flow rate of the system. (Fig. 19)

4. **Ratio stations** can be added to any multiple feeder installation, adding versatility to the system.

Gravimetric feeders can be controlled by computer, if required. (Fig. 20) Computerization of a process has been applied in many ways. These would include simple data acquisition, open and closed loop control, and sequential (on-off) control, also known as batch sequencing. Closed loop control is divided into two categories, supervisory and direct digital control (DDC). Closed loop control allows the computer to manipulate the process variable directly. In supervisory control, the computer calculates an optimum set point, which it then sends to the remote set point input of the analog controller. The controller then uses that set point together with all three modes of control to calculate in analog fashion the rate of material being delivered to process.

In direct digital control, the three modes of control are stored as part of the computer program by which the computer itself calculates the desired feed rate and sends this signal directly to the feeder.

Before any specific equipment selections are made, the designer should consider the following:

1. Only select standard equipment whenever possible. Standard equipment facilitates the initial delivery, reduces the initial cost, and assures an ample supply of spare parts when required.

2. All equipment should be integrated. No single piece of equipment or handling system is applicable to all problems. Care should be given to the integration of all components to assure that the combination will yield an effective overall material handling system.

3. Plan for the future. Try to anticipate your future needs with respect to equipment sizing, etc.

4. Don’t overlook maintenance. In selecting the proper process equipment, one should consider the maintenance of the system involved.

With all points being considered, the final choice and type of equipment to be used in the processing industries is left ultimately up to the user. Today’s modern technology and techniques have made gravimetric and/or volumetric feeding concepts an accepted, reliable and accurate means of metering material into process.

**REFERENCES**


